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APPLICATION OF MULTI-TEMPORAL MERIS FR AND ASAR WS DATA FOR LARGE SCALE VEGETATION MONITORING IN THE WEST AFRICAN SAHEL ZONE

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ABSTRACT

This paper presents results achieved within the AQUIFER project from applying a remote sensing approach for regional scale vegetation monitoring in the Sahel. The present study is focussing on vegetation monitoring over parts of Niger, Nigeria and Mali, three countries sharing the common Iullemeden Aquifer System. This Aquifer system is affected by progressive over-extraction, water quality degradation, human induced pollution, associated with soil degradation, and the impacts of variability and climatic change. The specific vegetation types in these arid regions are good indicators for environmental changes. In many parts of the Sahel there are no continuous ground truth measurements available to allow statements about the extension of vegetation. Earth Observation data may provide the only approach to detect and analyse long-term changes. This study demonstrates the performance and suitability of ENVISAT MERIS-FR and ASAR-WS data for this purpose. The application of radar capabilities to detect the moisture content and optical information for the phenological state monitoring of the vegetation is demonstrated. Land cover classification maps of four different points in time within one growth period were generated using a rule based (object oriented) classification approach. Additionally, the changes between the four different dates as well as the seasonal vegetation dynamics were analysed.

INTRODUCTION

The Sahel is the transition zone between Sahara desert and an area where in the presence of rainfall agriculture is possible. This area is characterized by important interaction between climate variability and socio-economic key factors like agriculture and water resources. The transboundary area of interest SAI (Système d'Aquifères d'Iullemeden) is affected by progressive over-extraction, water quality degradation, human induced pollution, associated with soil degradation, and the impacts of variability and climatic change. Studies in this region identified desertification and land degradation as a possible cause for the persistent drought in the Sahel. The specific vegetation and

the open surface water bodies in these arid regions are good indicators of environmental change. Long time land cover analysis allows monitoring the negative results from over-extraction of the available water resources as well as the vegetation decrease by human interventions.

This research includes the detection of the land use at four different dates within one growing season as well as the changes between these points in time. To reach these targets, two different groups of classification types were chosen. The first group consists of land cover and land cover change products. The second group consists of pre-classification change products, focused on seasonal dynamics. As remote sensing data two instruments from the ENVISAT satellite - MERIS and ASAR - are used. Therefore, this research shall

demonstrate the performance and suitability of a synergetic usage of radar data and optical data as well as the power of satellite remote sensing for long-term and large scale vegetation monitoring.

1. Aquifer – Project Background

The ESA financed AQUIFER project is one of the individual demonstrator projects of TIGER. ESA launched the TIGER initiative in 2002 as a CEOS (Committee on Earth Observation satellites) contribution to assist African countries to overcome water-related problems and to bridge Africa's water information gap using satellite data. This AQUIFER study is embedded in the programmatic framework of the Data User Element (DUE), which aims to bring together the scientific research community working on pilot projects and the operational service suppliers providing Earth Observation (EO) products and sustainable services corresponding to the operational needs of the wider user community.

In many parts of the Sahel there are no continuous ground truth measurements to allow statements about the extension of vegetation and open water bodies. Earth Observation data may provide the only way to detect and analyse long-term changes. Thus, the main objective of the Aquifer project is to support the involved national authorities and international institutions with EO based technology in order to manage internationally shared water resources and aquifers better. Above that, another aim is to strengthen overall and integrated water management practices.

2. Test site iullemeden & characteristic

The transboundary area of interest SAI (Fig. 1) covers approximately 525.000 km², including parts of Niger, Nigeria, and Mali. It is located within (1°00'–10°00') E and (10°00'–19°00') N (GAF AG 2006) and comprises parts of the northern and southern Sahel (WEZEL et al. 1999).

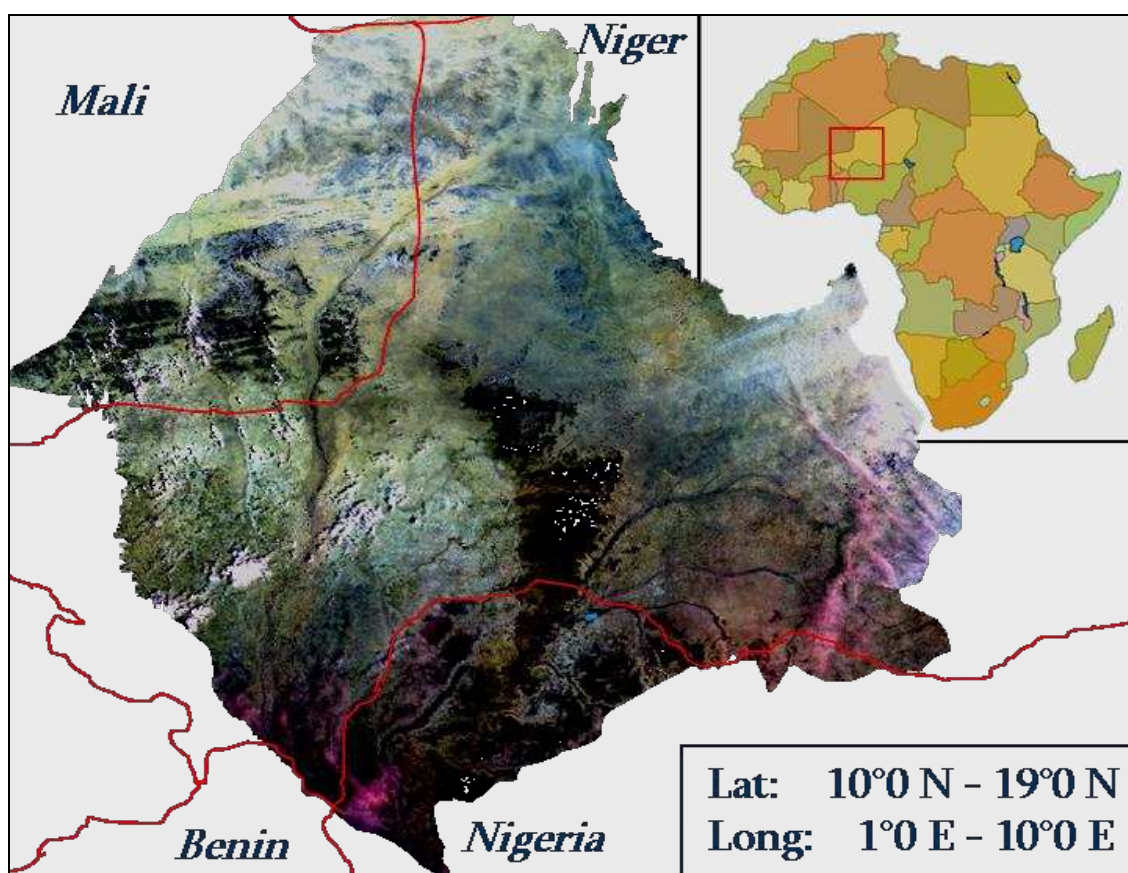


Fig. 1. Area of interest SAI (MERIS data: Oct05 - R[11]-G[7]-B[5])

The climate in the SAI basin is characterised by the annual cycle of rainfall. A short rainy season with high precipitation from June to September is followed by a long drought from October to the middle of May. Figure 2 shows the mean precipitation (1995-2004) in the area of interest within the rainy season (June 1 – September 30) based on the NOAA/CPC RFE climatology Method (LOVE et al. 2004).

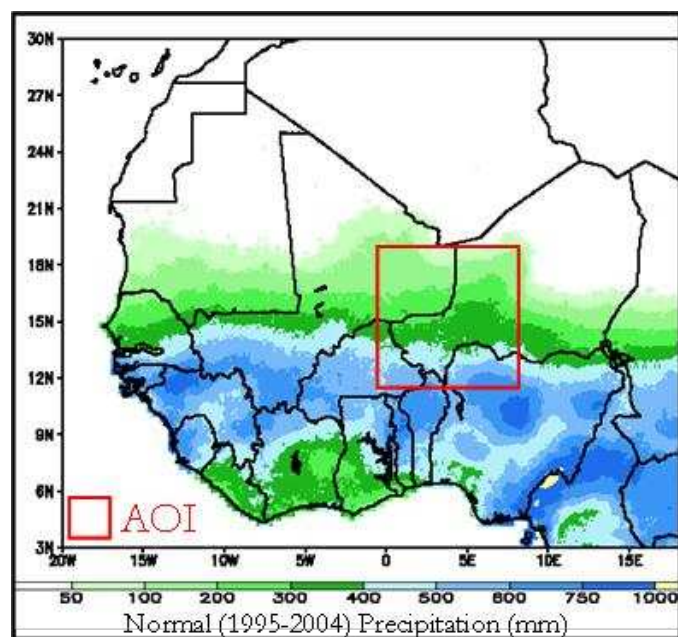


Fig. 2 Mean precipitation in the area of interest SAI within the rainy season (CPC 2008)

Water resources from dams or groundwater are used in the drought for irrigation, but individual water bodies may dry out completely and large areas are only cultivated during the rainy season. In the rainy season the number of rainy days and the amount of annual rainfall decrease from the south to the north. The floodplains of the main rivers are mostly inundated during this season. The vegetation adapts to the annual cycle of rainfall with a slight temporal delay. The physiognomy of the vegetation zones changes from contracted vegetation in the Sahara to tree, shrub or grass savannas in the Sahel. During the long drought a huge part of the vegetation withers. These bald trees and bushes show no photosynthetic activity until the next rainfall. The sparse tree density as well as the intensive pasturing results in an increased soil and vegetation erosion in the whole region (WEZEL et al. 1999).

3. Data sets & processing

The SAR data was acquired in Wide Swath Mode (VV) and delivered as L1 product. This data product includes slant range to ground range corrections and covers a continuous area along the imaging swath. The MERIS data was delivered as full resolution (FR) level 1b data. MERIS L1b products provide geocoded Top-Of-the-Atmosphere (TOA) radiances with a pixel spacing of 260 m at nadir. A swath width of 1150 km allows the coverage of the entire earth surface within an interval of 3 days. The instrument measures the TOA radiance in 15 bands within the visible and near infrared range from 408 nm to 905 nm. As reference and validation data a Landsat-7 mosaic from 2000 and a NigeriaSat-1 scene from 2006 were available. To compare the results with other large scale products the GLC2000 land cover dataset was used for the whole area. A direct field-data sampling was not feasible.

First of all, the EO-data were pre-processed on the base of commonly used techniques. GAMMA Remote Sensing Software was used for the data extraction, the radiometric calibration (including speckle filtering) and the reprojection of the SAR data. To reduce the speckle effect for an adequate estimate of σ^0 , the *Frost* filter was applied. The performance of speckle reduction has been evaluated based on the *Filter Index*, the *Speckle Noise Index* and the *Equivalent Number of Looks*. The *Edge Keeping Index* was used to verify the texture and edge preservation (ZHIYONG et al. 2004). Due to the limited availability of SAR scenes, the typical seasonal dependency of the vegetation cover and the differences between the subswaths, the application of a multi-temporal filtering has not been satisfactory. For the geocoding information, the SRTM 90 m elevation data of the Consortium for Spatial Information (CGIAR-CSI), processed to fill data voids, was used. Due to the sensitivity of the backscattering coefficient to the terrain, the topographic normalisation process proposed by STUSSI et al. 1995 was applied. For a full coverage of the area of interest the scenes were combined to create a consistent mosaic across the region. After the processing of the individual SAR

scenes one problem remained: It was impossible to completely adjust the backscatter intensity of the individual subswaths.

The BEAM Software was used for the data extraction, the orthorectification and the reprojection of the MERIS data. To enable a comparison and to mosaic the different images, it was necessary to convert the TOA radiance values into surface reflectance (SR). In order to correct for atmospheric influences, the *Simplified Method for Atmospheric Corrections (SMAC)* has been used (RHAMAN & DEDIEU 1994). The orthorectification was applied by using the GETASSE30 elevation data as a source for the required geocoded information. Additionally, the MERIS Level 2 biophysical vegetation variables ($fAPAR$, $fCover$) were generated by the MERIS TOA-VEG Processor (BARET et al. 2006). The product layers have been co-located with the corresponding orthorectified MERIS image. Similar to the ASAR data, the scenes were combined to create a consistent mosaic across the region.

3.1 Analysis of ASAR time series

The SAR data were well investigated with regard to their potential for land cover classification based on different commonly used methods.

Generally, open surface water is considered easy to detect on radar images. This point of view seems to be an oversimplification, since it is known that C-band is very sensitive for roughness on water surfaces due to windy conditions. Typically water bodies appear in SAR images as areas with a low backscattering, thus a simple threshold could be used for a successful extraction. Small waves on the water surface result in higher backscatter intensity (DE CHIARA et al. 2006) and hinder the distinction between water and the remaining areas. Multi-temporal analysis of all available ASAR mosaics as well as the additional use of texture features did not improve the distinction. Furthermore, the detection of water bodies using the ASAR data was limited by the low geometric resolution, which also prevented the detection of the mostly narrow rivers.

The specific SAR technique offers a useful method to detect urban areas. The geometric

characteristics of buildings causes dihedral scattering, leading to very high backscattering and enabling the classification of urban areas using the ASAR backscatter information. Detection of urban areas with MERIS data in the SAI region is not practicable because the houses are primarily built of natural materials. This limits the separation between urban areas and the surrounding land cover by radiometric features. The multi-temporal mean image of the available ASAR mosaics (May05, Sep05 and Dec05) allowed the extraction of an urban area mask (Fig. 3).

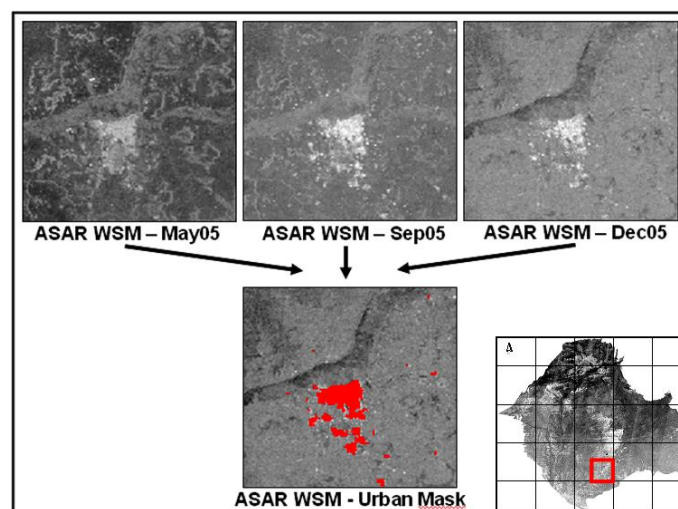


Fig. 3 Extraction of the ASAR urban mask - Example of Sokoto/Nigeria

Based on a *Stratified Random Sampling* approach using *PCI Geomatica*, error matrices were used to assess the urban area classification accuracy for the whole area (100 random points), which results in an overall accuracy around 86%. Due to the differences between the subswaths in the ASAR WS data (see Ch. 3) the distinction between vegetation types based on the ASAR data was anticipated.

3.2 Analysis of MERIS time series

Vegetation indices provide an excellent basis for the recording of vegetation dynamics and their phenology as well as for the distinction between vegetation and non-vegetation. Due to the inclusion of absorption characteristics of the vegetation, which are related to the seasonal and annual variations in the photosynthetic activity, vegetation indices are very suitable for the

detection of seasonal vegetation dynamics. For all MERIS mosaics the indices NDVI, SAVI (Soil Adjusted Vegetation Index) and the MTCI (MERIS Terrestrial Chlorophyll Index) were calculated (Eq. 1, 2).

$$SAVI = \frac{R_{Band13} - R_{Band7}}{R_{Band13} + R_{Band7} + L} \cdot (1 + L) \quad (1)$$

$$MTCI = \frac{R_{Band10} - R_{Band9}}{R_{Band9} - R_{Band8}} \quad (2)$$

The NDVI was calculated from the MERIS bands 13 (865 nm) and 7 (665 nm). Because of the low vegetation density in the SAI region, the value 1 was used as soil-brightness dependent correction factor L for the calculation of the SAVI. Compared to the NDVI, the SAVI highlights the vegetation areas more properly. The MTCI is sensitive to a wide range of chlorophyll contents and provides a good distinction between different photosynthetic activities (DASH & CURRAN 2005).

Besides the introduced vegetation indices, the biophysical vegetation variables fAPAR and fCover were generated. The TOA-VEG Processor derives fAPAR and fCover directly from the MERIS L1b data (see Ch. 2). The fAPAR value (Fraction of Absorbed Photosynthetically Active Radiation) refers only to the green parts of the canopy (leaf chlorophyll content > 15µg.cm⁻²) and varies from 0 (low) to 1 (high). fAPAR is comparable with the already existing MERIS Level 2 fAPAR product MERIS Global Vegetation Index (MGVI). fCover is the fraction of green vegetation covering a unit area of horizontal soil. It only considers green vegetation (leaf chlorophyll content > 15µg.cm⁻²) and varies from 0 (bare soil) to 1 (full cover) (BARET et al. 2006).

4. Land cover and & land cover change classification

For the land cover classification of the four acquisition dates, different classification approaches have been tested. Supervised (MLC), unsupervised (k-means clustering) and rule based (object oriented) classifications using the MERIS bands and the ASAR backscatter intensity as well as several indices (see Ch. 3.2) have been considered. The qualitative comparison and

analysis of the several classifications results pointed out that the rule based (object oriented) approach using *Definiens Professional* is suited best for the land cover classification. As first the multi-scale segmentation of the input data was accomplished to generate image objects (*segments*) as basis of the object-oriented classification. The *multiresolution segmentation* algorithm was applied as segmentation mode and except for the urban mask (weight '0') all input layers were included in the segmentation (weight '1'). In both regions a *scale parameter* of '2' and a *homogeneity criterion* of '1' were used as segmentation parameter for the first segmentation level. For the second level a *scale parameter* of '10' and a *homogeneity criterion* of '1' was used. During the progress of the classification hierarchy the basic classes *water*, *green vegetation* and *other* were subdivided into the extended classes *water*, *clouds*, *urban*, *low green vegetation*, *high green vegetation*, *floodplain vegetation* and *other*. Table 1 shows the LCCS-standard class description for the extended classes (LCCS 2005).

Tab. 1 LCCS standard description for extended classes

Class (LCC Label)	LCC Label (Example:LCC Formula)
Water	Water bodies (natural & artificial) <u>A1-A4 // A1-A5</u>
Urban	Artificial surfaces and associated areas <u>A4-A13A16</u>
Floodplain Vegetation	Natural And Semi-Natural Aquatic or Regularly Flooded Vegetation <u>A2A20B4C3 // A1B2XXC3D2E1-E4 // A2A14 // A3B2XXC2D2-C4C10C15C18 A2A20B4C3</u>
High Green Vegetation	Cultivated and managed areas Mosaic: cropland/ shrub or grass cover Shrub cover, closed-open, deciduous <u>A3A20-A2 //A4A20//A5A20//A6A20</u>
Low Green Vegetation	Sparse herbaceous or sparse shrub cover Cultivated and managed areas Herbaceous cover, closed-open Shrub cover, closed-open, deciduous <u>A1A14 // A4A20-A21 // A5A20 // A6A20</u>
Non-Photosynthetic Vegetation	LCC - code assignment not possible (as described in Ch. 4)
Clouds	LCC - code assignment not possible (as described in Ch. 4)
Other	Bare areas <u>A6B16-A6B3</u>

Urban areas were defined by means of the extracted ASAR urban mask (see Ch. 3.1). For the generation of the cloud mask the high reflection of clouds and haze in the MERIS band 1 and the MERIS cloud ratio (band11/band10) have been used (PREUSKER et al. 2006). Open water bodies are

characterised by very low reflection in the near infrared and particularly by very low values in the NDVI. The major limitation of the water body mask results from the low geometrical resolution of the MERIS data (260 m). Hence in the mapped pixel their spectral signature is mixed with the signature of the surrounding land cover. Thus most of the rivers could not be detected. The example below shows the changes of a selected water body during the period of three acquiring dates. It is clearly visible that during the drought (May) the water body is dried up completely (Fig. 4), whereas the maximum extend of the water body is reached in October at the end of the rainy season. It is possible to monitor the extension of open water bodies in these arid regions in terms of the annual rate of change. These changes are probably a good indicator of a possible environmental change in the Sahel.

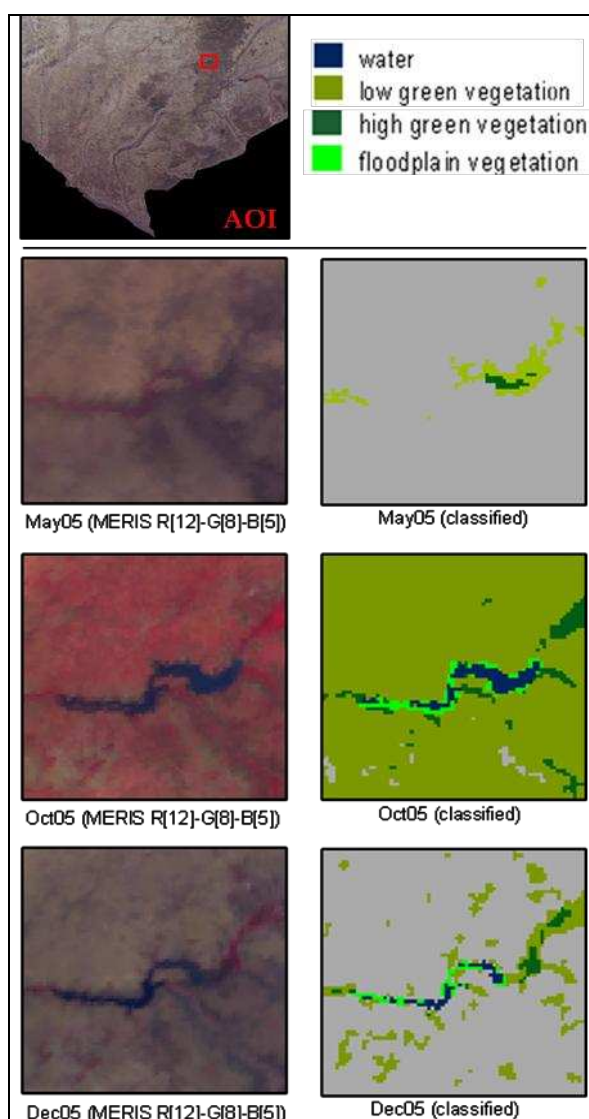


Fig. 4 Change of water extension in the AOI

Green vegetation was classified using the NDVI. High green vegetation and low green vegetation differ by a higher photosynthetic activity of the high green vegetation, which is indicated by high values of the MTCI and the fCover. The MERIS ratio $(\text{band14} - \text{band13}) / (\text{band14} + \text{band13})$ enabled the classification of the inundated floodplains, which are intensively cultivated by flood-recession agriculture (ADAMS 1993 in HARTENBACH & SCHUOL 2005). Thus, the detected floodplains in the SAI region can be classified as *floodplain vegetation*. The radiometric properties of the floodplains are a mixture of the spectral characteristics of water and vegetation. The above-presented MERIS ratio emphasises inundated floodplains as well as water bodies (*Water (Floodplain)*). A higher NDVI differentiates the floodplain vegetation from water bodies.

During the drought the main part of the vegetation has no photosynthetic activity and appears as bald area with dry trees and bushes. Therefore it is to assume that the maximum extend of photosynthetic active vegetation (*green vegetation*) in the four individual maps represents the expansion of non-photosynthetic vegetation for the whole season. Adding the green vegetation masks of all 4 acquisition dates, a mask for the extent of *non-photosynthetic vegetation* was generated. The classification results showed strong varieties in the photosynthetic activity of the vegetation (Fig. 5), based on the climate conditions in the region (see Ch. 2).

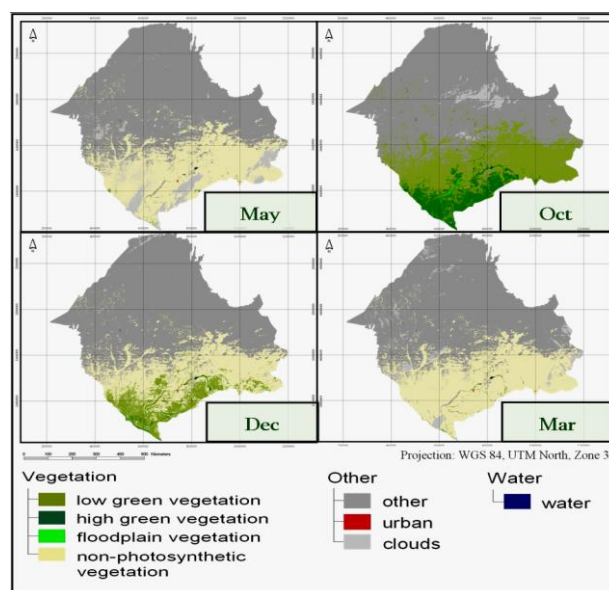


Fig. 5 Extended land cover classification results

The area related analysis of the land cover classification includes the area of green vegetation and water at the four acquisition dates (Fig. 6).

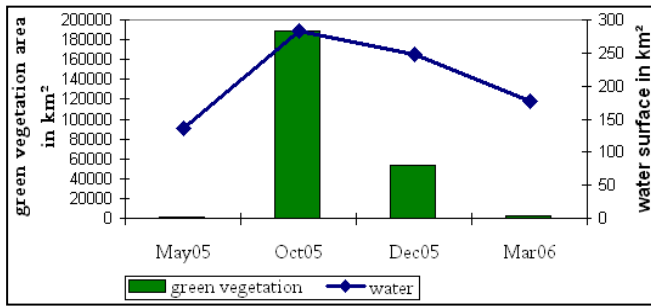


Fig. 6 Vegetation and water changes (May05-Mar06)

The change between these dates point out the seasonal dynamics and show that it is possible to monitor the extension of vegetation and its phenological dynamic. These informations are important indicators to state ecological changes and local climate fluctuations. Furthermore, the four green vegetation masks were fused to a land cover change map. This map shows and distinguishes areas which feature green vegetation at one, two, three or four acquisition dates. This additional information is a helpful utility according to the characterization of land cover classes, particularly in view of land use.

Based on the *Stratified Random Sampling* approach (see Ch. 3.1), error matrices were used to assess the land cover classification accuracy and are summarized for all acquisition dates in Table 2 (100 random points/ class).

Tab. 2 Accuracy assessment for classification results

Acquisition Date	May05	Oct05	Dec05	Mar06
Basic LCC	x	x	x	x
Overall Accuracy	0,81	0,78	0,82	0,84
Kappa	0,75	0,70	0,76	0,79
Extended LCC	x	x	x	x
Overall Accuracy	0,76	0,74	0,71	0,76
Kappa	0,72	0,69	0,66	0,72

For the comparison with the GLC2000 product (FRITZ et al. 2003) two indicators, the correlation coefficient r and the $RMSE$ are derived for each class membership (Eq. 3, 4). The $RMSE$ reveals the absolute differences between fuzzy class estimates of GLC2000 and the land cover classification maps in opposition to r , which is a measure of relative correspondence.

$$r = \frac{\sum_{i=1}^N (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^N (x_i - \bar{x})^2 \cdot \sum_{i=1}^N (y_i - \bar{y})^2}} \quad (3)$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^N (x_i - y_i)^2}{N}} \quad (4)$$

N = Number of elements
x = GLC2000 map
y = Land cover classification map

The main land cover classes also confirm with the GLC2000 map. But in comparison to the GLC2000 water and urban area classes, the presented extended land cover classification maps shown very plainly the more accurate and detailed results.

5. Seasonal vegetation dynamic

The NDVI as well as the fAPAR follows the specific vegetation cycles dependent on the yearly rain cycles in the SAI region. Figure 7 shows the NDVI for one growth period - the increase of the NDVI from March to October and after that the decrease of the NDVI from October to December and from December to March.

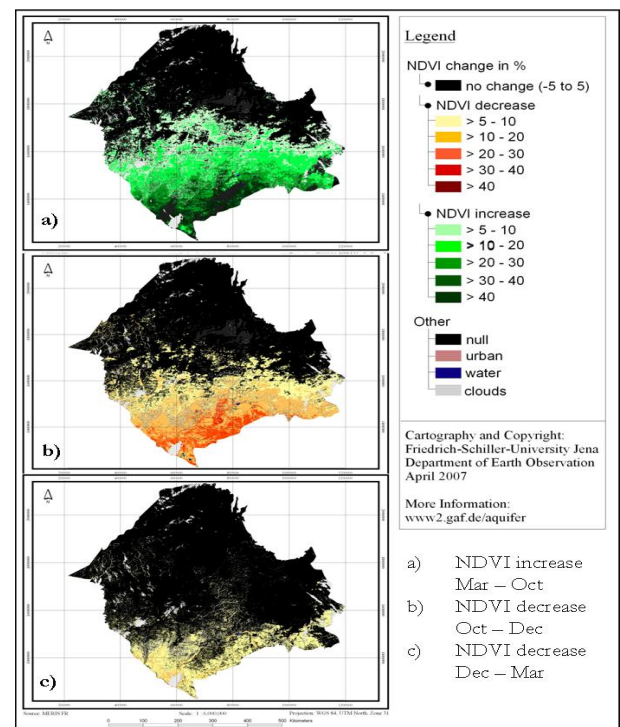


Fig.7 NDVI change Maps for one growth period

To distinguish groups of vegetation by their seasonal (temporal) behaviour the k-means clustering algorithm was used. Beforehand, a common cloud mask for all four MERIS mosaics was generated. After cloud masking, the NDVI and fAPAR mosaic layers were stacked to one multi-temporal dataset. For the k-means clustering different numbers of initial classes were tested (4, 8, 10, 14). Ten initial classes are best suited to distinguish the multi-temporal NDVI and fAPAR layerstacks into groups of vegetation of different temporal behaviour. To label the different classes, thresholds were defined basing on visual interpretation of the image data and a statistical analysis of the clusters. Because of the strong radiometric effect of bare soil, the threshold for photosynthetic activity was defined with an NDVI > 0. High photosynthetic activity was defined with an NDVI threshold > 0.15. Figure 8 depicts a subset of the NDVI-seasonal change map.

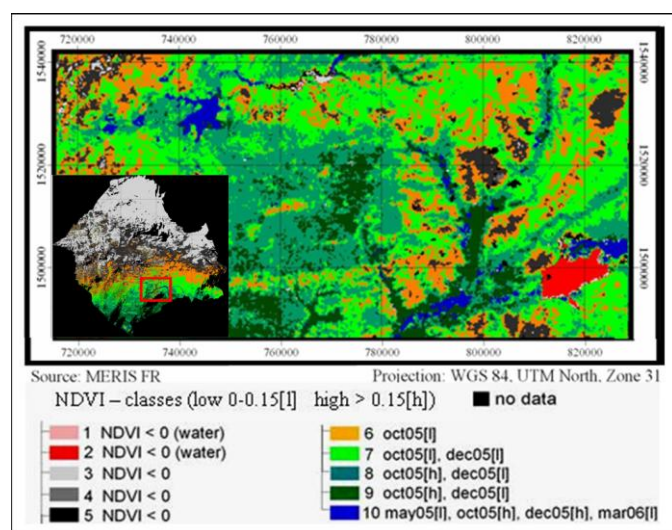


Fig. 8 NDVI – Seasonal Change Map

Because of the direct relation between the vegetation and available water resources such vegetation dynamic maps allows statements about water resources and changes in water availability. In the case of long time series, these informations are important indicators to make reliable statements about ecological changes or local climate fluctuations. For instance, it could offer help for the decision making for an improved water management in the Sahel and a basis for the estimation of water resources used for irrigation.

CONCLUSIONS

This study demonstrated the performance and suitability of ENVISAT MERIS-FR and ASAR-WS data for the purpose of monitoring long-term changes regarding to land cover. It was shown that large scale land cover monitoring using ASAR & MERIS data provides an appropriate tool to observe vegetation extension in the course of a year. Furthermore, a methodology for the extraction of the vegetation's phenology was presented.

In the case of long time series it allows monitoring the effects of Sahelian drought, overgrazing and the local impact of climate change and help the government take a look at past trends in terms of deforestation, reclaimed land and new settlement areas to determine the long term affect and implement corrective measures.

For this purpose, the GlobCover project offers a very interesting free available facility. GlobCover provides bimonthly pre-processed MERIS mosaics for 2005, which are a good data-base for large scale coverage with a high temporal resolution. Considering that in the future similar products are available, you have an outstanding tool to monitor the whole Sahel zone and to analyse the land cover change in terms of climate change and the human impact.

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